The NASA SCI Files™
The Case of the
Powerful Pulleys

Segment 3

The tree house detectives continue investigating pulleys, and Bianca continues researching various engineering careers for her presentation. Everyone is positive that pulleys are the answer to getting Jacob into the tree house. However, they are a little confused about how many pulleys to use. They decide to contact Ms. Gail Nowell's class, a NASA SCI Files™ Kids Club, in Raleigh, North Carolina. Now the tree house detectives think they have all the information they need to lift Jacob. Fortunately, they test their apparatus before putting Jacob in it, and they quickly realize that they have not considered safety features. The tree house detectives visit Ms. Rines, a safety engineer at NASA Langley Research Center in Hampton, VA. Ms. Rines suggests that they also need to consider human factors and sends them to see Dr. Kara Latorella, a human factors engineer, also with NASA Langley Research Center. Back at the tree house, the detectives have used their last pulley, but Jacob is still too heavy to lift. They stop by Dr. D's lab in hopes that he will be able to help them reduce the force needed to lift Jacob and to help them figure out what to do with all that rope from the pulley system.

Objectives

The students will

- investigate how pulleys make work easier.
- design a safe and comfortable apparatus to lift a weight.
- understand how human factors affect the design of a product.
- construct a lever to lift a large weight.
- investigate the use of gears.
- understand friction.
- investigate changing technology through history.

Vocabulary

apparatus - the equipment or material for a particular use or job

compound machine - a machine consisting of two or more simple machines

gear - a toothed wheel that developed from the wheel and lever

human factors - study of how people behave physically and psychologically in particular environments and with certain products or services

Video Component

Implementation Strategy

The NASA SCI Files™ is designed to enhance and enrich the existing curriculum. Two to three days of class time are suggested for each segment, to fully use video, resources, activities, and web site.

Before Viewing

1. Prior to viewing Segment 3 of *The Case of the Powerful Pulleys*, discuss the previous segment to review the problem and what the tree house detectives have learned thus far. Download a copy of the Problem Board from the NASA SCI Files™ web site and have students use it to sort the information learned so far.
2. Review the list of questions and issues that the students created prior to viewing Segment 2 and determine which, if any, were answered in the video or in the students' own research.
3. Revise and correct any misconceptions that may have been dispelled during Segment 2. Use tools located on the Web, as was previously mentioned in Segment 1.
4. Focus Questions - Print the questions from the web site ahead of time for students to copy into their science journals. Encourage students to take notes during the program to answer the questions. An icon will appear when the answer is near.
5. What's Up? Questions - Questions at the end of the segment help students predict what actions the tree house detectives should take next in the investigation process and how the information learned will affect the case. These questions can be printed from the web site ahead of time for students to copy into their science journals.

View Segment 3 of the Video

For optimal educational benefit, view *The Case of the Powerful Pulleys* in 15-minute segments and not in its entirety. If you are viewing a taped copy of the program, you may want to stop the video when the Focus Question icon appears to allow students time to answer the question.

After Viewing

1. Have students reflect on the "What's Up?" questions asked at the end of the segment.
2. Discuss the Focus Questions.
3. Have students work in small groups or as a class to discuss and list what new information they have learned about work, energy, force, and simple machines. Organize the information, place it on the Problem Board, and determine whether any of the students' questions from Segment 2 were answered.

Careers

safety engineer
human factors engineer
structural design engineer
chemical engineer
architect

4. Decide what additional information is needed for the tree house detectives to determine what is the best method of getting Jacob into the tree house. Have students conduct independent research or provide students with information as needed. Visit the NASA SCI Files™ web site for an additional list of resources for both students and educators.
5. Choose activities from the educator guide and web site to reinforce concepts discussed in the segment. Pinpoint areas in your curriculum that may need to be reinforced and use activities to aid student understanding in those areas.
6. If time did not permit you to begin the web activity at the conclusion of Segments 1 or 2, refer to number 6 under "After Viewing" on page 13 and begin the Problem-Based Learning activity on the NASA SCI Files™ web site. If the web activity was begun, monitor students as they research within their selected roles, review criteria as needed, and encourage the use of the following portions of the online, Problem-Based Learning activity:

   Research Rack - books, internet sites, and research tools

   Problem-Solving Tools - tools and strategies to help guide the problem-solving process.

   Dr. D's Lab - interactive activities and simulations

   Media Zone - interviews with experts from this segment

   Expert's Corner - listing of Ask-An-Expert sites and biographies of experts featured in the broadcast
7. Have students write in their journals what they have learned from this segment and from their own experimentation and research. If needed, give students specific questions to reflect upon, as suggested on the PBL Facilitator Prompting Questions instructional tool found in the educator's area of the web site.
8. Continue to assess the students' learning, as appropriate, by using their journal writings, problem logs, scientific investigation logs, and other tools that can be found on the web site. Visit the Research Rack in the tree house, the online PBL investigation main menu section "Problem-Solving Tools," and the "Tools" section of the educator's area for more assessment ideas and tools.

Resources

Books

Dahl, Michael: *Pulleys.* Bridgestone Books, 1996, ISBN: 1560654457.

Maynard, Christopher: *Jobs People Do*. DK Publishing Inc., 1997, ISBN: 0789414929.

Peterson, John Lawrence: *The Littles and the Trash Tinies*. Scholastic Inc., 1993, ISBN: 0590465953.

Seller, Mick: *Wheels, Pulleys, & Levers.* Gloucester Press, 1993, ISBN: 0531174204.

Web Sites

Marvelous Machines
A list of experiments for levers, wheel and axles, and inclined planes. http://www.henry.k12.ga.us/cur/simp-mach/resources.htm

Combined Pulley
An explanation about the advantages and disadvantages of pulleys, including a moving model. http://www.smartown.com/sp2000/machines2000/pulley4.htm

Mathematics Activities With Ropes and Pulleys
A series of three activities for students to explore the mechanical advantage of pulleys. http://www.cpo.com/CPOCatalog/RP/rp_math.htm

PBS Teacher Source—Mathematics of Bicycles
“Wheel Figure This Out” is an activity offered by PBS Teacher Source that builds mathematical skills by comparing various features of the bicycle. http://www.pbs.org/teachersource/mathline/concepts/neighborhoodmath/activity3.shtm

Activities and Worksheets

Powerful Pulleys

Purpose

To understand that pulleys reduce the amount of force needed to lift an object

Materials (per group)

two double pulleys
string
pennies
cup with attached string
clamp and poles from which to hang the pulley system
500 gram mass (weight)
balance
calculator

Procedure

1. Use a balance to find the mass of the bottom pulley system and the attached weight, which is called the load. Record the mass in the chart below.

Object	Mass
Load (Mass of pulleys + 500 g)	

2. Attach the string to the hook on the bottom pulley.
3. Loop the string over the top pulley and attach the cup to the string.
4. Hang the weight from the hook on the bottom pulley. (See Diagram 1)
5. Begin placing pennies in the cup, continuing until the cup balances the weight without anyone having to hold it.
6. Continue placing pennies in the cup until the cup moves. Note: If the cup begins to move and then stops, give the cup a little downward tap. If the cup resumes its motion and moves a good distance, don't add any more pennies. If the cup moves only a few cm and then stops again, you will need to add another penny or two until it moves with a little tap.
7. Place the cup with pennies on the mass balance and record its mass to the nearest gram. The mass of the pennies plus the cup is called the total mass.
8. Repeat steps 5-7 for three more trials and record results in data chart (p. 44). Before each trial, remove 5 or 6 pennies from the cup.
9. Find the average mass for the four trials and record in the data chart. Your answer should be to the nearest gram.
10. To repeat the experiment using 2 strings, attach the string to the top pulley, go around one bottom pulley and one top pulley and then attach the cup to the string. See diagram 2.
11. Now repeat steps 5 through 9 to determine the mass required to lift the load, when it is supported by 2 strings.
12. To find the mass required when using 3 strings, attach the string to the bottom pulley, go around one top pulley, bottom pulley, and the top pulley. See diagram 3.
13. Repeat steps 5 through 9.
14. To find the mass required using 4 strings, attach the string to the hook on the top pulleys and go around one bottom, followed by a top pulley, then the other bottom pulley, and finally the remaining top pulley. See diagram 4.
15. Repeat steps 5 through 9.

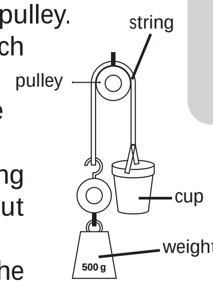

Diagram 1

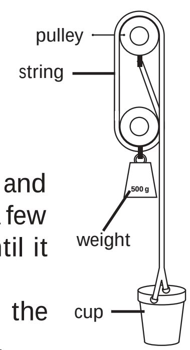

Diagram 2

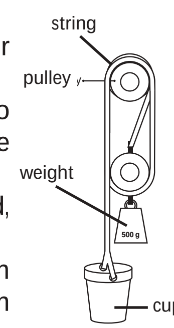

Diagram 3

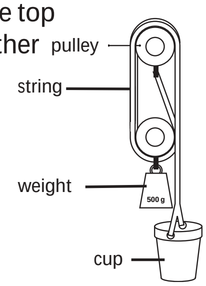

Diagram 4

Data Chart: Total Mass

Number of Strings	Trial 1	Trial 2	Trial 3	Trial 4	Average Total mass
Example:	212 Grams	213 Grams	211 Grams	212 Grams	212 Grams (212 + 213 + 211 + 212) ÷ 4
1 String					
2 Strings					
3 Strings					
4 Strings					

16. Share your results with the rest of the class and find the class average to the nearest gram.

Group Averages for Total Mass

	1 String	2 Strings	3 Strings	4 Strings
Group 1				
Group 2				
Group 3				
Group 4				
Group 5				
Group 6				
Class Average				

Conclusion:

1. Was the total mass required to move the pulley always less as the number of strings increased?
2. The theory states that the total mass required to lift the load with a pulley system can be found by dividing the load by the number of strings supporting the bottom pulley. Use a calculator to divide the load (Load = mass of bottom pulleys + 500 grams) by the number of strings in each experiment. Record the actual average total mass required to lift the load for each. Find the difference between the two numbers and record.

Number Strings	Load ÷ Number of Strings	Actual Total Mass	Difference
Example: 1	523 ÷ 1 = 523 g	554g	31g
1			
2			
3			
4			

How do you explain the differences between your class's experimental values for Total Mass and the values listed above for Load ÷ Number of Strings?

Safe, Sneaky Snacks

Purpose

To design a safe apparatus to lift a specified load

Teacher Note

Prior to performing the activity, you will need to construct a 10-cm x 30-cm x 3-m rectangular vent from cardboard for students to use for testing their apparatuses. Allow students one-two days to research and design an apparatus. Provide basic materials or have students bring supplies from home to complete their design. Rubrics and other evaluation tools are provided on the NASA SCI Files™ web site that may be printed and given to students for assessment.
http://scifiles.larc.nasa.gov/educators/index.html

Materials

- science journal
- eggs
- metric rulers
- encyclopedias
- internet access
- string
- cardboard
- shoe boxes
- scissors
- scraps of material
- cotton
- foam
- glue
- tape
- thread spools or pulleys
- plastic eggs

Procedure

Shannon and Blair are trying to sneak snacks up to their playroom without their little sister's knowledge. They have decided to set up a pulley system inside a 10-cm x 30-cm air-conditioning vent. The playroom is located 3 meters directly above the kitchen. They have to make sure that their snacks don't fall since the snacks are eggs! To help Shannon and Blair, you need to design an apparatus to lift the snacks quietly and safely.

1. In your group, discuss the situation, determine "what you know" and create a list in your science journal. To help in your design process, a copy of the Design Log can be obtained from the NASA SCI Files™ web site <http://scifiles.larc.nasa.gov/educators/tools/pbl/design_log.html>
2. Reach a consensus about "what you need to know" and conduct research using books, the Internet, and other available resources.
3. Design your apparatus, creating detailed drawings, descriptions, and a materials list needed for your design. Note: At your teacher's discretion, materials may be brought from home to help construct your apparatus.
4. Be sure that you have considered and addressed all the appropriate safety issues.
5. To construct your apparatus, gather the materials needed and work as a team to create a safe apparatus for your egg snacks.
6. Once the apparatus is completed, conduct a test run with a plastic egg to make sure your apparatus is safe for your real egg.
7. If problems are encountered in your test run, redesign and make changes as needed. Conduct a second test run. Repeat until test run is successful.
8. Lift your egg in the apparatus.

Conclusion

1. What safety precautions did you take to ensure that the egg would survive the trip up the vent?
2. What type of backup plan would you make if the apparatus fell down the vent past the kitchen and into the basement?
3. What materials worked the best in this project?
4. What materials are the safest?
5. How did your research help you design the apparatus?
6. How can the tree house detectives make their lift chair safer?

Extension

Test the students' apparatuses in an "egg drop" contest to see which ones best protect the egg from a fall.

Keeping It Human

Materials

backpacks
weight scale
print resources
Internet
science journal

Purpose

To understand human factors involved in designing a product

Procedure

The young astronauts' club has just received a grant to purchase laptop computers for each member of the club. However, the laptops are heavy, and your teacher is concerned that students may experience physical problems from carrying them to and from school each day. You and the other members want to enjoy your laptops at home each night, so you decide that you need to design a backpack that would both carry your laptop safely and keep you from being injured.

1. Visit Cornell University's Ergonomics Web site at <http://ergo.human.cornell.edu/MBergo/intro.html>, and/or conduct additional research by using other print and online resources.
2. Review what Dr. Latorella discussed with the tree house detectives about human factors.
3. Brainstorm various human factors that should be considered in designing a backpack.
4. Observe various backpacks and discuss the designs of each.
5. Discuss the amount of weight that will be carried in the backpack (laptop plus books, notebooks, and so on).
6. Explore the relationship between the weight of a backpack compared to the weight of the person wearing it. (Divide the weight of the backpack by the student's weight.)

Example:

Backpack weight	Body Weight	% of weight carried
22 kg	129 kg	17

7. Conduct research to determine what percentage is a safe amount to carry.
8. Calculate the amount of weight to be carried in the backpack and your weight to determine the percentage of weight to be carried. Is this a safe percentage?
9. Draw a detailed design of your backpack.
10. Share your design with the class and explain why you designed it as you did.

Conclusion

1. What is a safe percentage of weight to carry in a backpack?
2. Why is it important not to carry more than a certain amount of weight on your back?
3. What human factors did you consider in your design?

Load-Lifting Lever

Purpose

To help students understand that a lever can be used to lift a weight with less effort

Materials

2 in x 6 in x 6 ft board (5 cm x 15 cm x 180 cm)
small triangular block for fulcrum
marker
meter stick

Procedure

1. Measure the board and mark the center of the board with a marker.
2. Starting at the center of the board and working your way to one end, mark the board every 30 cm.
3. Label the center of the board "C." Label the next mark "1R," the third mark "2R," and the end "3R" (right side of the board).
4. Repeat for the other side of the board, labeling the marks 1L, 2L, and 3L (left side of the board). See diagram 1.
5. Place the triangular block (fulcrum) at the center mark of the board.
6. Place six same-sized textbooks (load) on mark 3R at the end of the board. This arrangement works best if you are able to "center" the books over the ends of the board.
7. Predict how many textbooks it will take to balance the load and record the number.
8. On the opposite end of the board at 3L, begin to stack the same-sized textbooks (force or effort) until the board balances. Record in data chart below.
9. Take all the books off the board.
10. Keeping the effort at the same place, repeat experiment with the load at a different point by centering the stack of six books (load) over mark 2R and by repeating steps 7-9. Note: To get the board to balance, you might need to adjust the position of the effort by a few centimeters.
11. Repeat steps 7-9, keeping the effort constant, but positioning the stack of books (load) over mark 1R.
12. Look at the data collected and find any patterns and/or relationships.
13. In the previous experiment, you moved the load closer to the fulcrum and applied the force or effort in the same place. Now you are going to keep the load constant and move where you apply force or effort. Predict any patterns that might be created and record in your science journal.
14. Place two textbooks (load) at the end of the board at mark 3R. Predict how many textbooks it will take to lift the load from the 2L mark. Record your prediction in your science journal.
15. Begin stacking textbooks (force or effort) at mark 2L, being sure to center them over the mark.
16. Continue to stack textbooks until the board balances. Record in data chart and take the books off the board.
17. Keeping the load at 3R, repeat steps 15-16 but this time center the books over mark 1L.

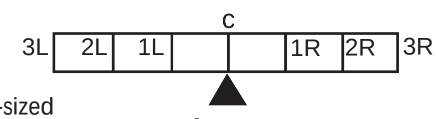

Diagram 1

Conclusion

1. What did the board represent? The triangular block? The six books lifted? The books used to do the lifting?
2. As you moved the load toward the center of the board, did it take more or fewer books to lift the six books (load)?
3. As you moved the force or effort toward the center of the board, did it take more or fewer books to lift the six books (load)?
4. In your science journal, create a graph of your data.

Data Chart

Effort at 3L—Load Varies	Prediction	Actual
3R		
2R		
1R		

Load at 3R-Effort Varies	Prediction	Actual
3L		
2L		
1L		

Extension

1. Predict where to place the fulcrum on the lever to lift your teacher. If your teacher will agree, test your prediction.
2. Research and explain Archimedes' Law of the Lever.
3. Research and explain the three classes of levers.

Creative Gears

Purpose

To use gears to make pictures and patterns

Materials

30-cm x 30-cm cardboard
drawing paper
colored pencils
corrugated cardboard
push pins
compass
scissors
glue
metric ruler
metric tape
35-cm x 35-cm foam board
various sized jar lids
nail
hammer

Procedure

1. Use the ruler to find the center of the 30-cm x 30-cm cardboard square.
2. Using the compass, draw a 22-cm diameter circle in the center of the cardboard.
3. Carefully cut out the circle to create a hole in the cardboard.
4. Use the tape to measure the circumference inside the circle.
5. Cut a strip of corrugated cardboard the circumference of the hole and 2 cm wide.
6. Glue the strip to the edge of the hole so that the corrugations face outward. Make sure that one edge of the strip is level with the edge of the hole. See diagram 1.
7. To create gear wheels, use the tape to measure the circumference of each lid.
8. Cut strips of corrugated cardboard to fit the circumference of each lid by 2 cm wide.
9. Glue strips onto the outer edge of each lid with the corrugation facing outward.
10. Using a nail, make 3-4 holes at different distances from the center in each lid. The holes need to be large enough for the point of your pencil to fit through.
11. Place a sheet of drawing paper on the foam board.
12. Place the corrugated cardboard square on top of the paper and use push pins to secure it in place.
13. Choose a gear wheel (lid) and place it on the drawing paper in the hole in the cardboard.
14. Choose a colored pencil and place the point through one of the holes in the gear wheel so that it touches the paper.
15. Hold the foam board firmly with one hand and use the pencil to push the gear wheel around the inside of the large hole. See diagram 2.
16. Continue to use different gear wheels and different colored pencils to create beautiful patterns and designs.

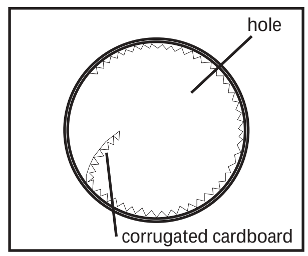

Diagram 1

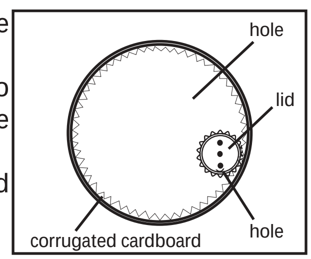

Diagram 2

Conclusion

1. Some patterns will repeat after just a few turns, while others may take many turns before they start again. Describe how you created patterns by using each gear wheel.
2. Explain how the number of teeth on the gears and the position of the pen hole affect the pattern.
3. What variables could you change to create different patterns?

Answer Key

Powerful Pulleys

1. Yes.
2. Answers will vary.
3. The difference between the two numbers is due to friction. Friction affects the amount of pennies needed to lift the mass and pulley. To overcome friction, more pennies must be added.

Safe, Sneaky Snacks

Answers will vary, but students should include safety measures that address the egg not rolling out of the apparatus, the apparatus not slipping, protection for the egg if the apparatus does fall, and any other criteria necessary.

Keeping It Human

1. 15 %
2. It is important not to carry more than that amount of weight on your back because additional weight can cause back injuries or stress to the spinal cord.
3. Answers will vary but might include the width of the straps, the ability to adjust the straps, the material the backpack is made of, and so on.

Load-Lifting Lever

Data Chart

1. The board represented the lever, the block was the fulcrum, the six books were the load or resistance,

Position of Load	Actual
3R	6
2R	4
1R	2

Position of Force/Effort	Actual
3L	2
2L	3
1L	6

the books used to do the lifting were the force or effort needed to lift the load.

2. As you moved the triangular block (fulcrum) toward the end of the board (load), it took fewer books (effort) to lift the six books.
3. It took more books to lift the load as you moved toward the fulcrum. If your force is 5 times further from the fulcrum than the load, then you multiply the force 5 times. The trade-off is that the distance you have to push down will be 5 times greater than the load distance (how far it moves up).
4. Graphs will vary.

Creative Gears

1. Answers will vary.
2. Answers will vary.
3. Some variables that can be changed to create different patterns are the size of the large hole, using different holes in the gear wheel, and using different sizes of gear wheels.

On the Web

That Sticky Friction

1. When you rubbed your hands together, you felt them get hot. Friction produces heat.
2. The rubber band should stretch longer when the box is resting on the flat surface. The flat surface should be the roughest surface and therefore have the most friction.
3. More force was required to start the box on the flat surface because the flat surface was the roughest surface creating the most friction. It takes more force to overcome more friction.
4. Lubricants reduce the amount of friction between two objects.
5. Answers will vary but might include motor oil, petroleum jelly, and grease.
6. Friction will increase the amount of force needed for the tree house detectives to lift Jacob with the pulley system.